

Linear Array Photodiode and Data Acquisition System Development for Multi-Point Line FLDI Measurements

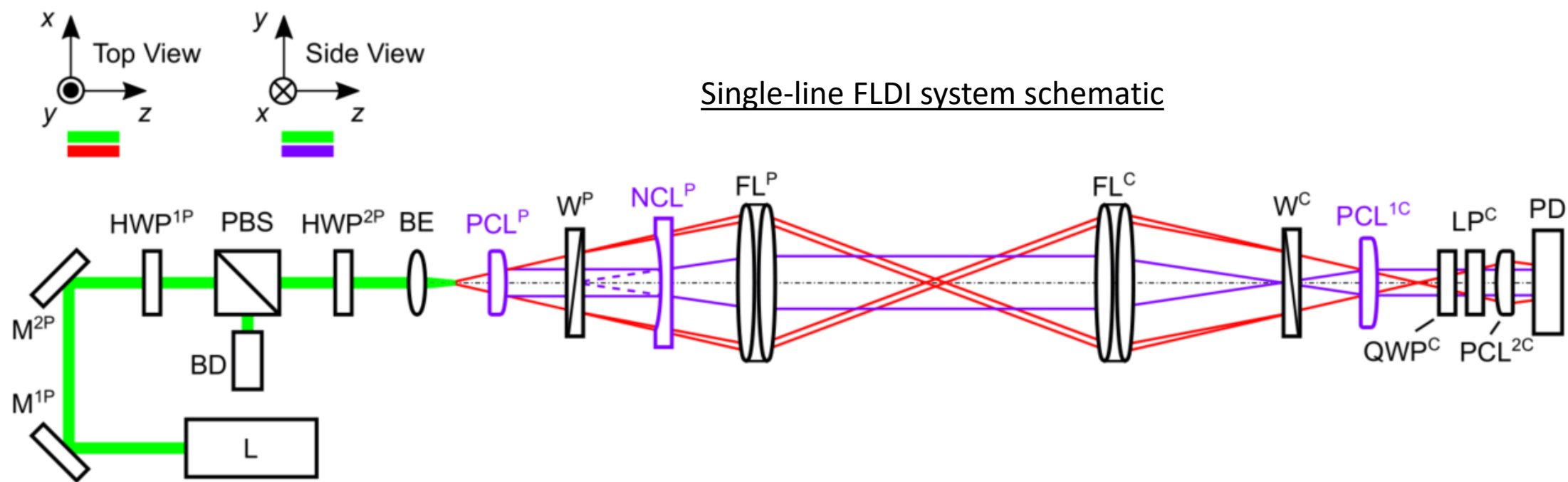
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Purpose of Line FLDI Data Acquisition System Further Development

- FLDI is a non-intrusive diagnostic that can make measurements of localized flow fluctuations out to very high frequencies
- After success of the 16-point line FLDI measurements, there was a desire to increase the spatial resolution of the measurement
- Selection of a 35-channel linear array photodiode motivated the need for a more robust method of data acquisition, including:
 - Dedicated printed circuit board for the photodiode for simple inclusion into existing line FLDI setup
 - Oscilloscope with sufficient channel count for simultaneous, high-speed acquisition of all channels
 - Amplifier circuit used to condition signal from photodiode output before input to oscilloscope
- Systematic testing of the various components instills confidence in the measurement system as a whole
- Final demonstration of the entire system incorporated in a line FLDI setup to measure the flow fluctuations from a compressed air jet

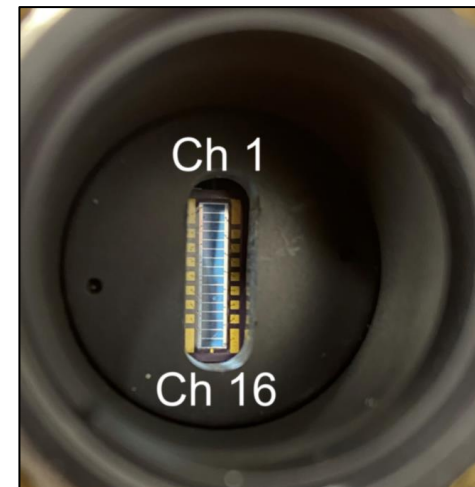


Single-line FLDI system schematic

For two-line system, see Refs. [1,2]

Sub-Assembly 1 // 35-Channel Linear Array Photodiode

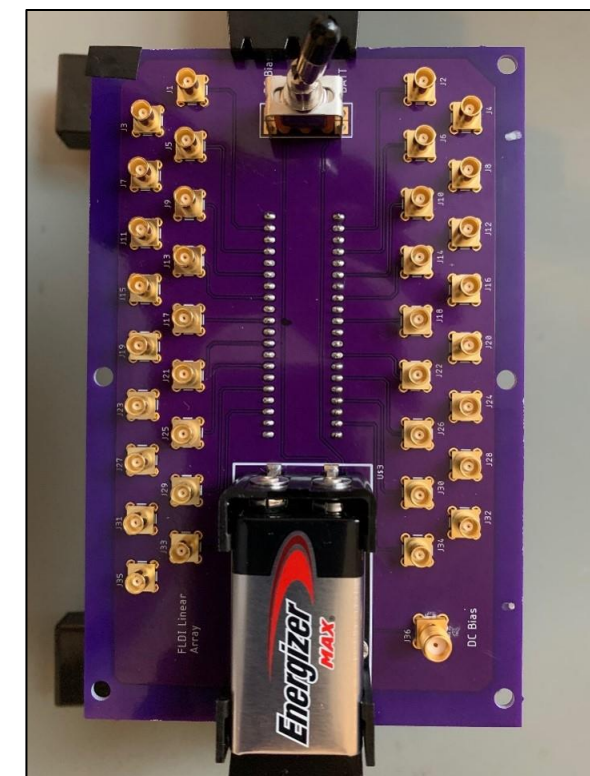
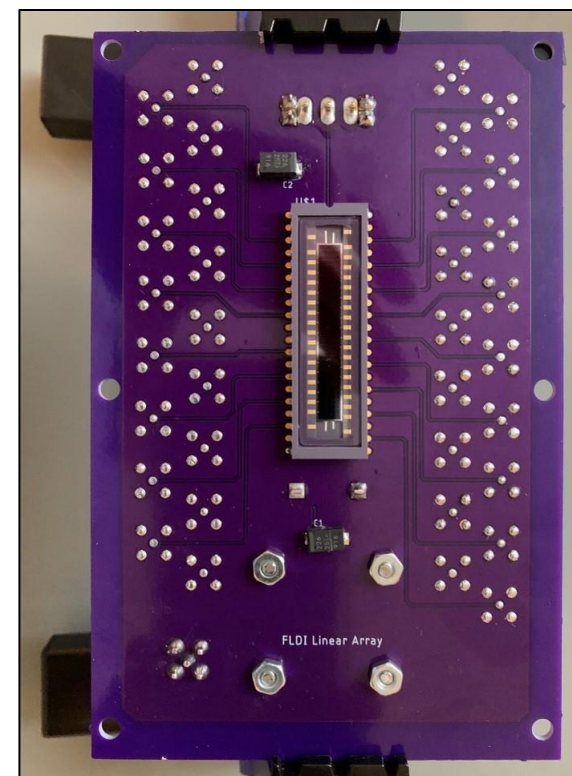
- Original line FLDI system used 16-channel linear array photodiode (Hamamatsu S8558)
 - 0.7 mm x 2.0 mm element size, 0.1 mm separation between elements
- Two primary reasons for switching to 35-channel linear array photodiode (Hamamatsu S4114-35Q)
 - 1) Increased channel count provides more spatial resolution of the flowfield
 - 2) Wider element size (0.9 mm x 4.4 mm, 0.1 mm separation) provides a larger buffer for lateral moment of the laser line due to beam-steering or vibrations
- Bottom images
 - Linear array photodiode mounted to center of board
 - Switch at the top allows for power supply selection between:
 - On-board 9 V battery
 - External DC power supply (input connector to the right of the battery)
 - Cable connections for each channel to connect to amplifier breakout boards



Left: 16-channel S8558

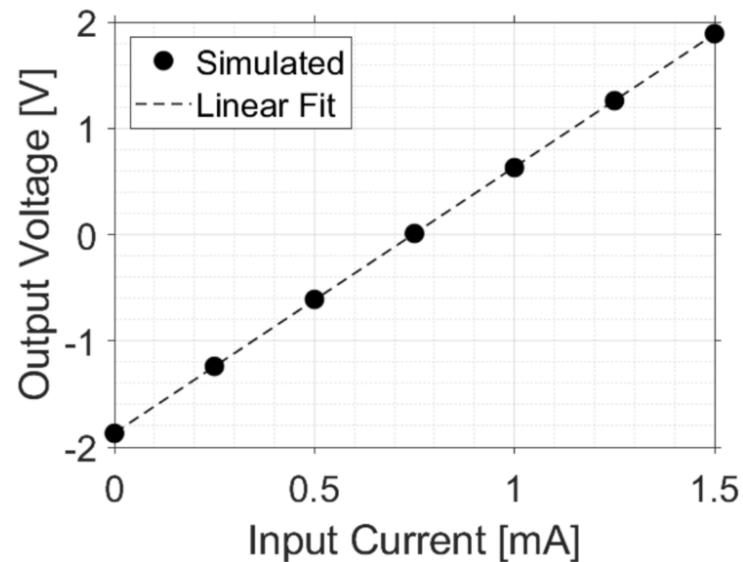
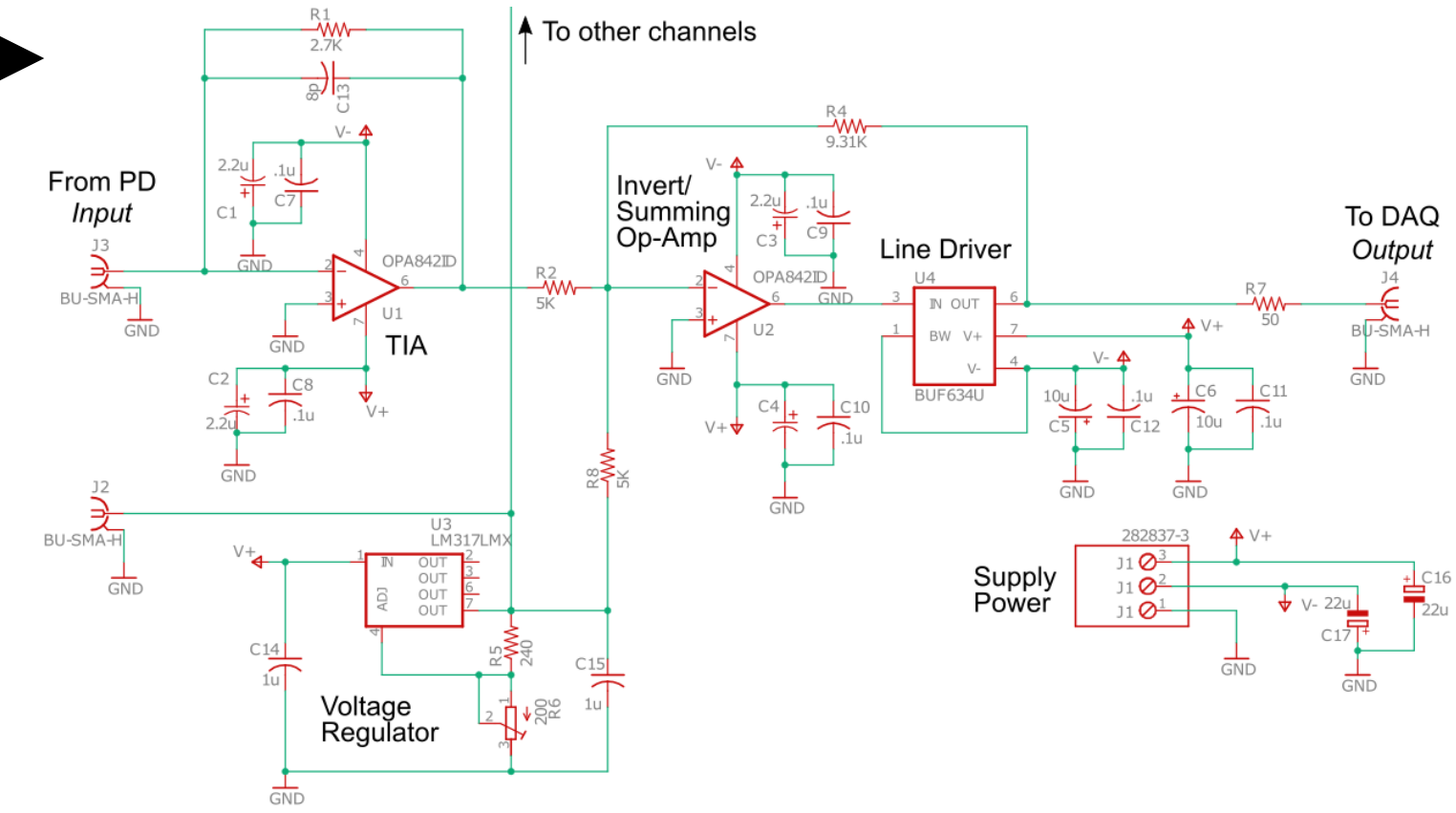
Bottom-Left: 35-channel S4114-35Q PCB front-view

Bottom-Right: 35-channel S4114-35Q PCB rear-view



Sub-Assembly 2 // Amplifier Breakout Board

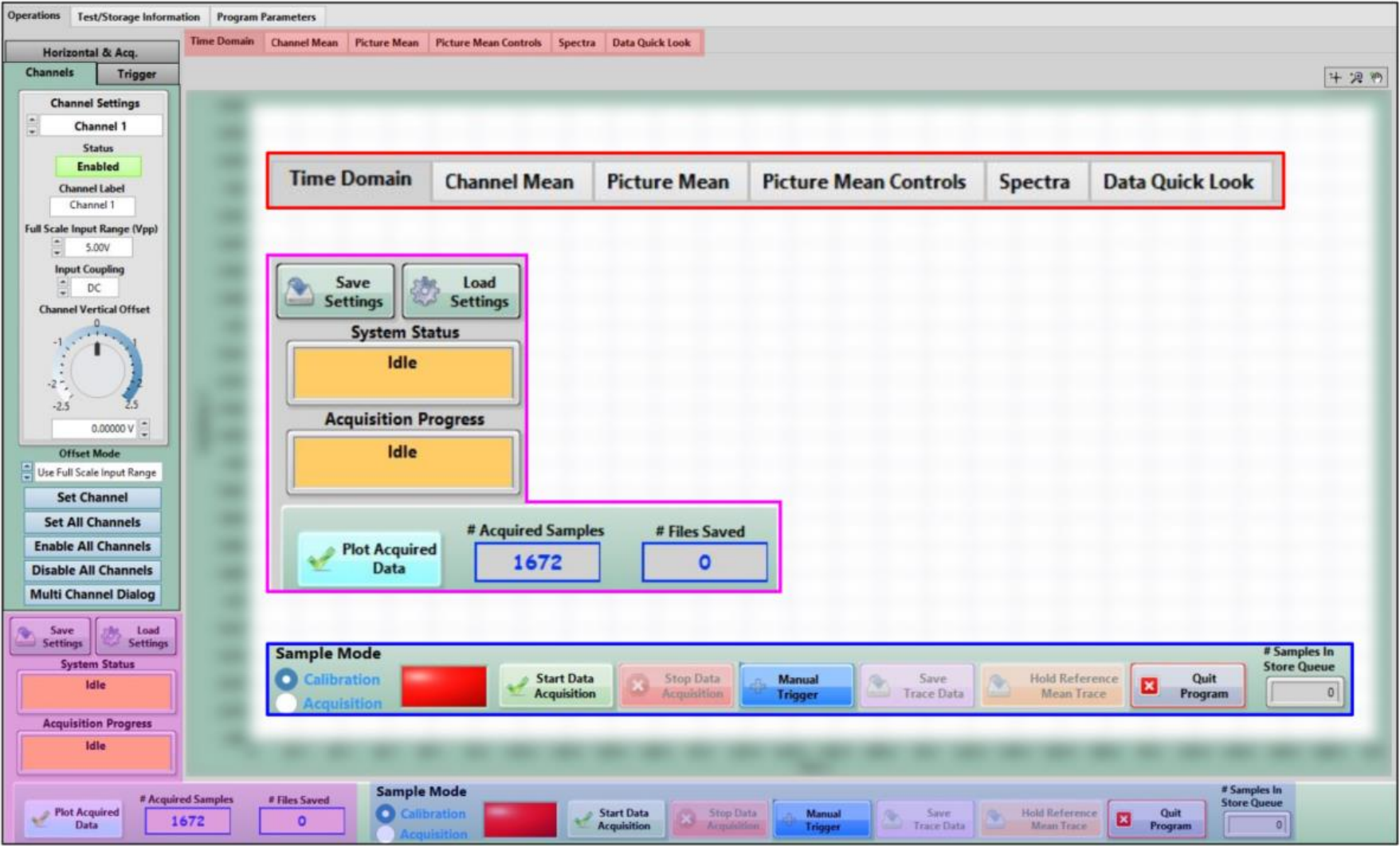
- Design of the amplifier circuit based on:
 - 1) Expected maximum output current from each channel of 1.5 mA
 - 2) Peak-to-peak full-scale voltage of data acquisition system of ± 2.5 V (selected ± 2 V for safer clipping margin)
- Amplifier PCB steps:
 - 1) Convert input current to output voltage (inverted and amplified)
 - 2) Invert voltage and shift to center about 0 V
 - 3) Confirm min/max expected input currents lie within min/max DAQ voltage limits



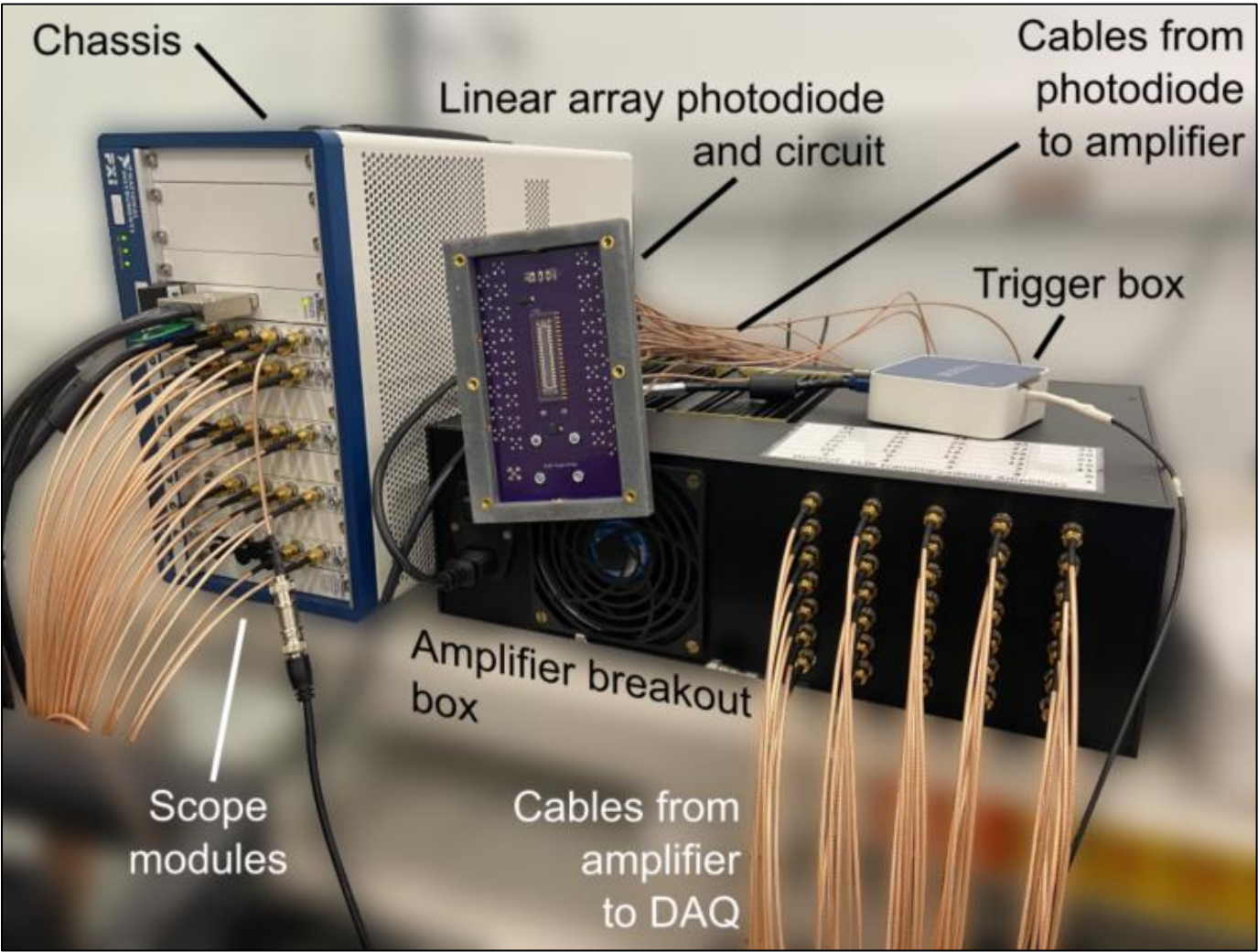
- Simulation of amplifier circuit shows proportionality of output voltage to an input current
- Linear regression:
 - Output voltage with no input current: -1.87 mV from y-intercept
 - Conversion proportionality constant: 2.5 V/mA from slope

- Existing 16-channel DAQ from previous line FLDI measurements was updated
- Simultaneous acquisition, plotting, and saving of up to 40 channels
- Each channel can have different acquisition settings
 - Full-scale input range
 - Input coupling
 - Voltage offset
- Plotting capabilities extended
 - Per-channel mean voltage for alignment
 - Extensive controls for mean voltage plotting
 - Time series power spectral density plotting
 - Data quick-look
- Separate calibration and acquisition mode

Main GUI Window

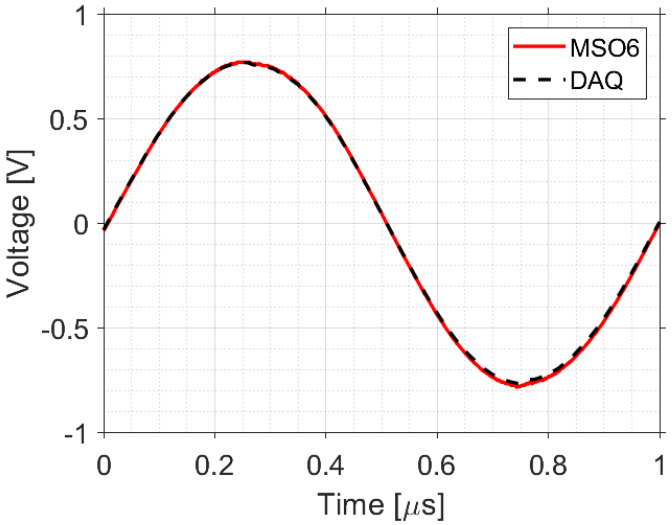
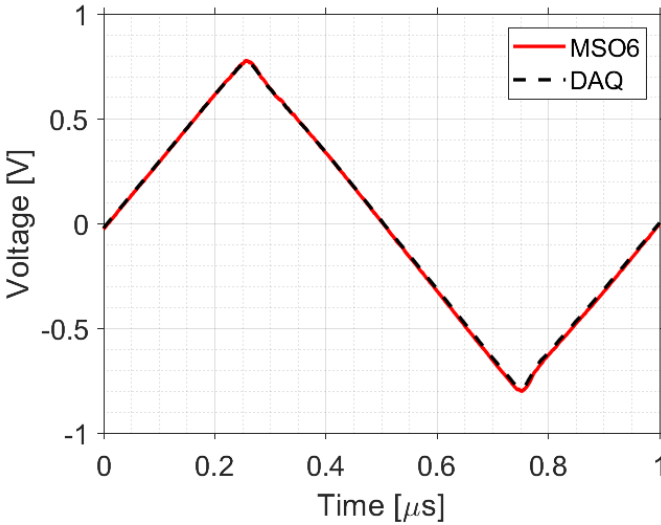
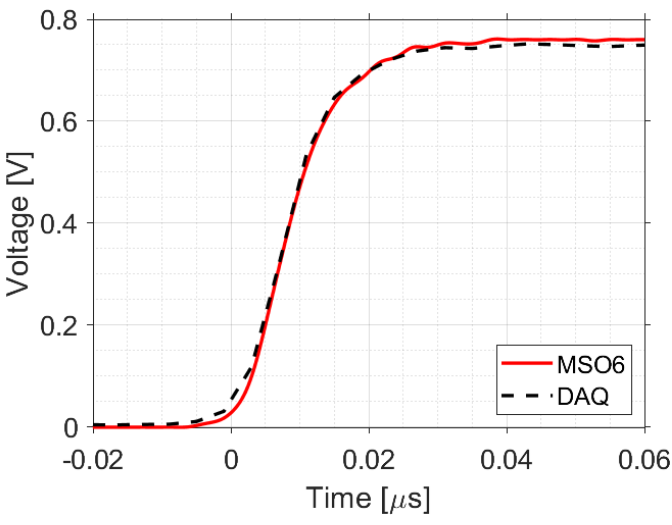
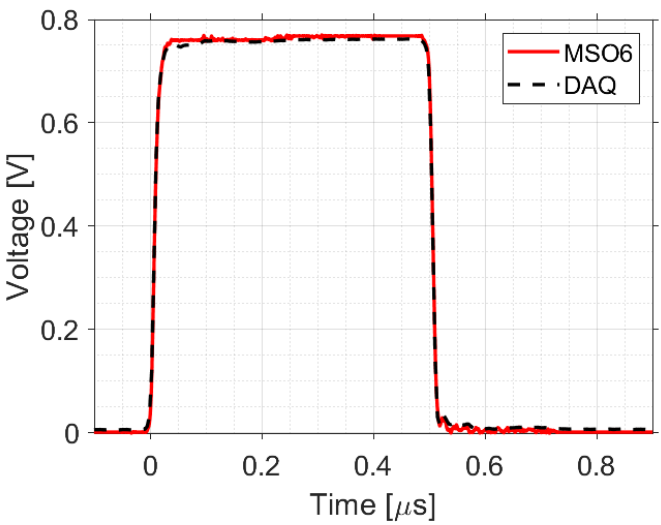
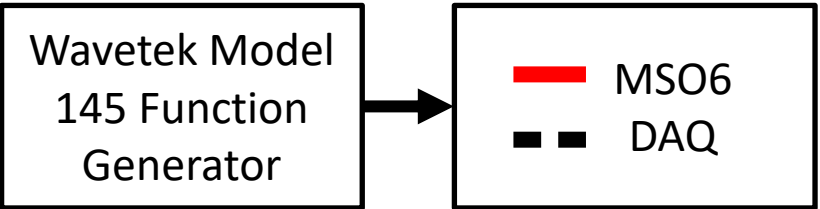


- Linear array photodiode mounted on its own PCB with reverse bias power selection
- Cables from rear of PCB connect to rear of amplifier breakout box
- Amplifier box houses:
 - Seven stacked 5-channel amplifier PCBs
 - Cooling fan
 - Power supplies for boards and fan
 - Toggle on/off switch
- Cables from front of amplifier box connect to five 8-channel high-speed oscilloscope modules housed in a chassis
- Controller module connects to computer for user control through specially-designed LabVIEW graphical user interface

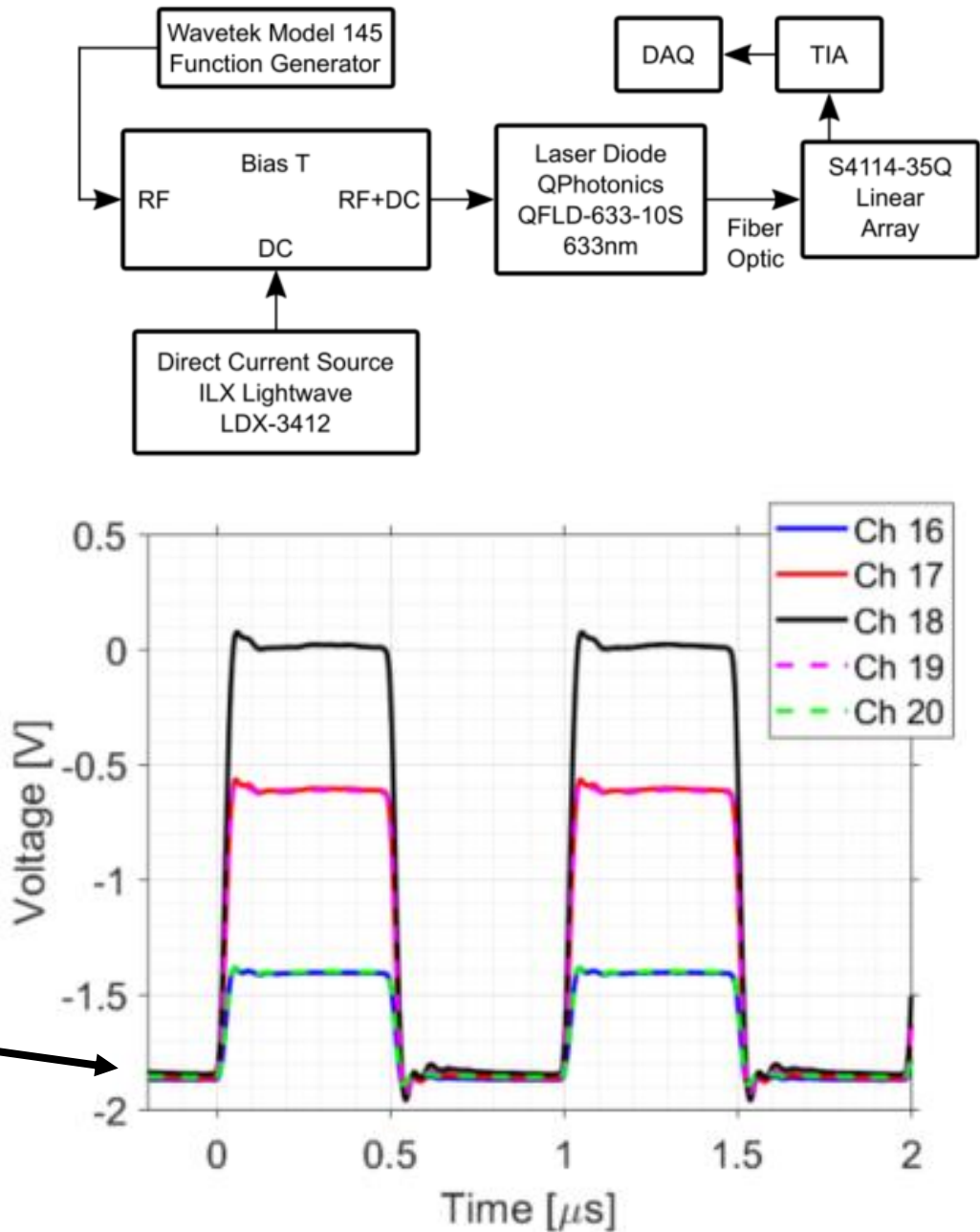


DAQ Operation Validation

- Verify that the DAQ (■ ■) operates correctly by comparing various input waveforms to data acquired with a previously used scope (MSO 6 series, — —)[3,4]
- Triangle, sine, and square 1 MHz waveforms result in same acquired data traces
- Gives confidence in DAQ hardware and acquisition software
- Rise time of square waveform from measurements is approximately 16.5 ns

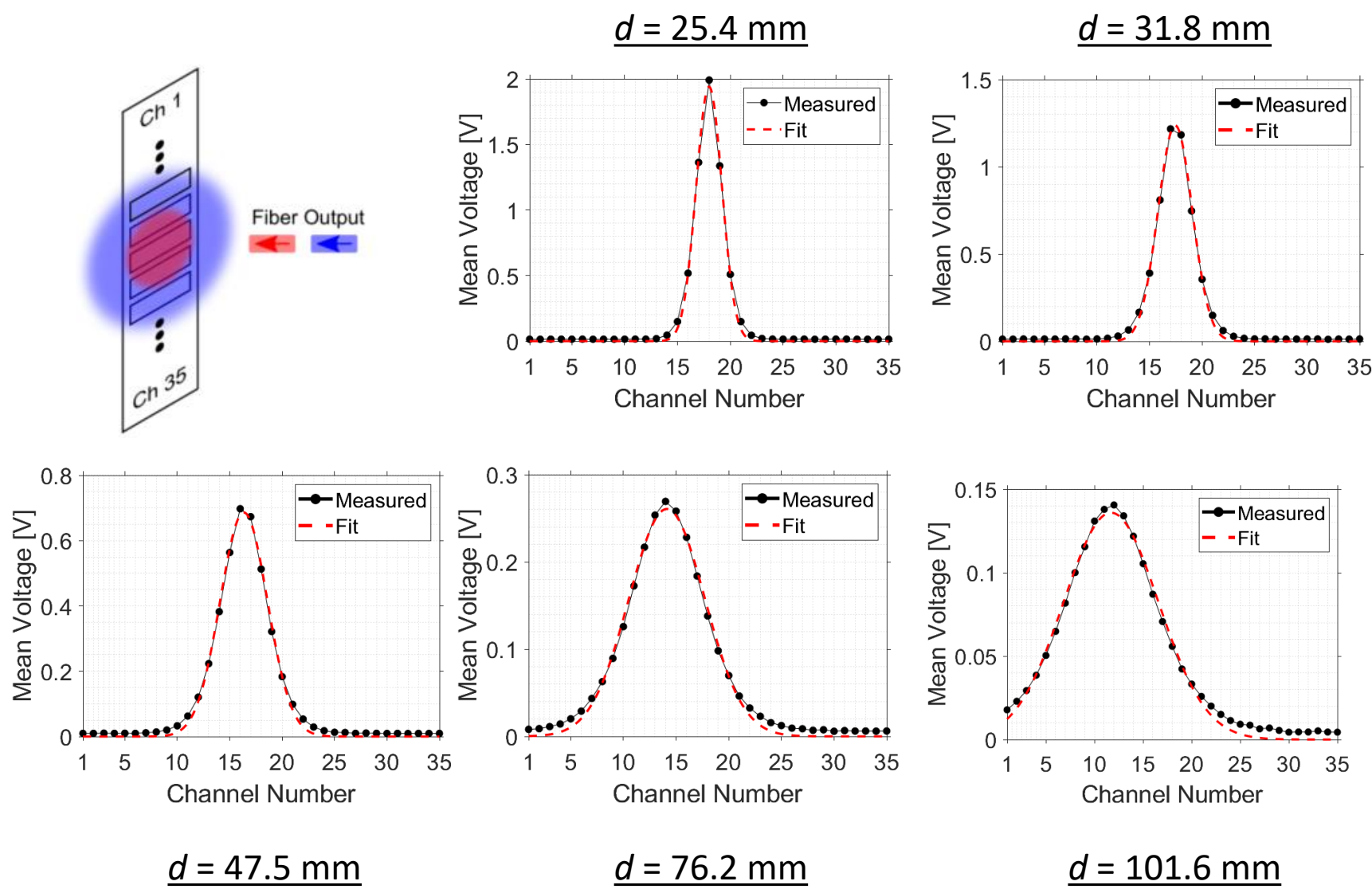


- Testing linear array photodiode and amplifier system (TIA in schematic) response to known input waveform
- Input waveform from tunable laser diode, modulated with 1 MHz square waveform
- Data acquired for duration of 2 μs at 250 MHz
- Laser incident on central five linear array photodiode elements (channels 16-20)
 - Central channel (**18**) has highest intensity, as is expected at the center of a Gaussian beam shape
 - Two adjacent channels (**17**, **19**) have lower, but equal voltages
 - Outer two channels (**16**, **20**) have lowest, but equal voltages
- Laser-off minimum voltage is -1.87 V, as is expected from the design of the amplifier circuit



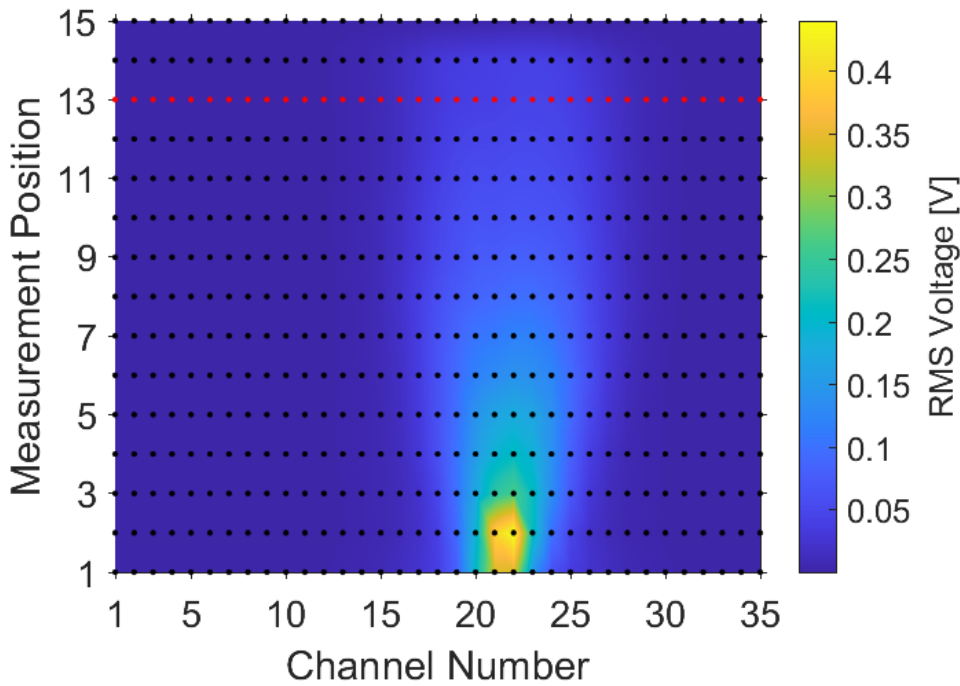
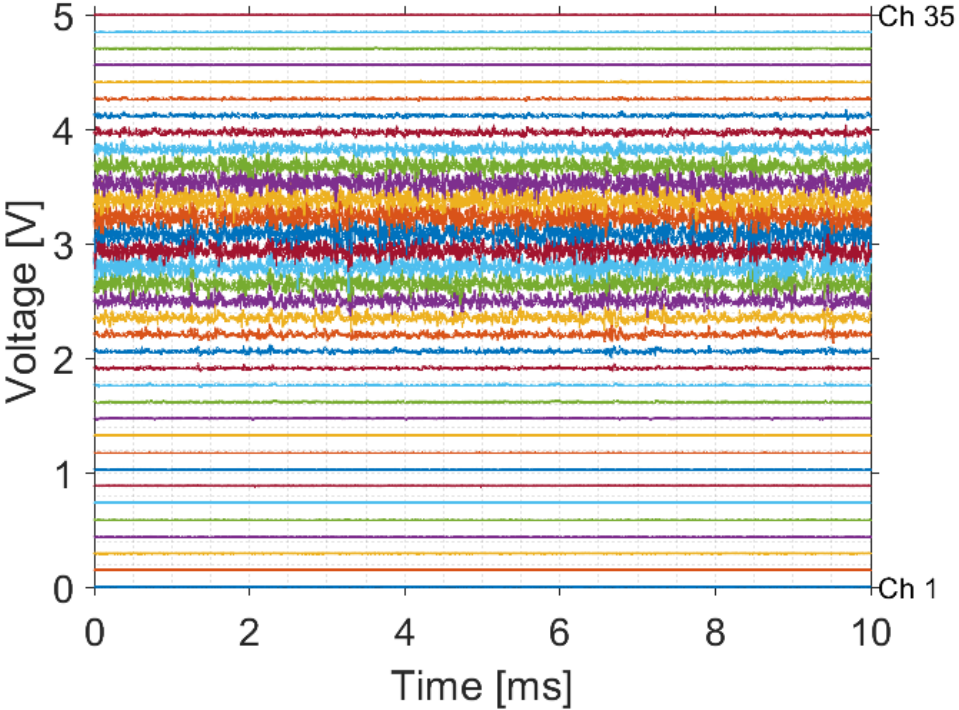
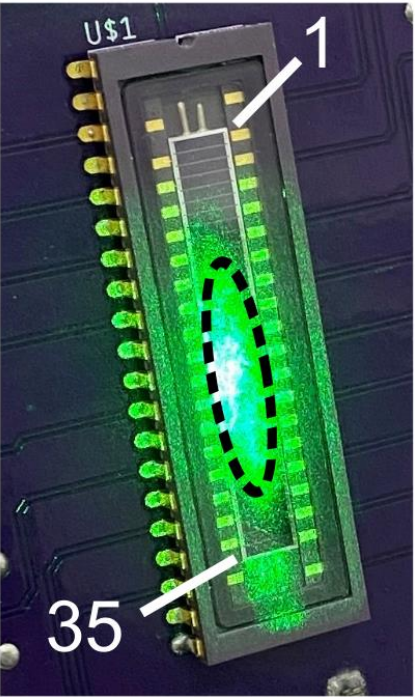
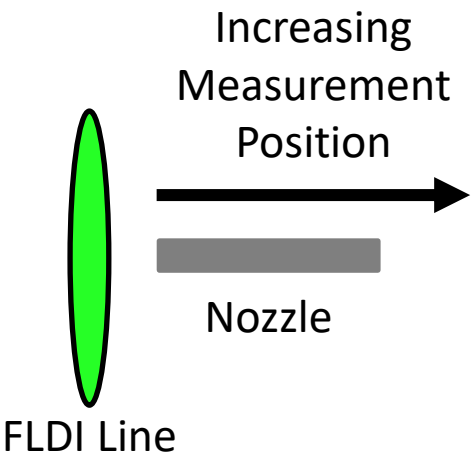
Linear Array Photodiode and Amplifier Testing

- Fiber output moved to five positions (d) relative to photodiode to measure incident beam shape
- Mean voltage is plotted for each channel sequentially
 - Mean voltage calculated from peaks of square wave
- As laser beam was moved farther from the photodiode:
 - Mean voltages decreased
 - Diameter of the beam shape widened
- Both results are consistent with a diverging incident beam
- Gaussian fit () matches measured data well
- Measurement of signals on adjacent channels gives confidence that crosstalk is negligible (*not pictured, see manuscript*)



Line FLDI Full System Testing

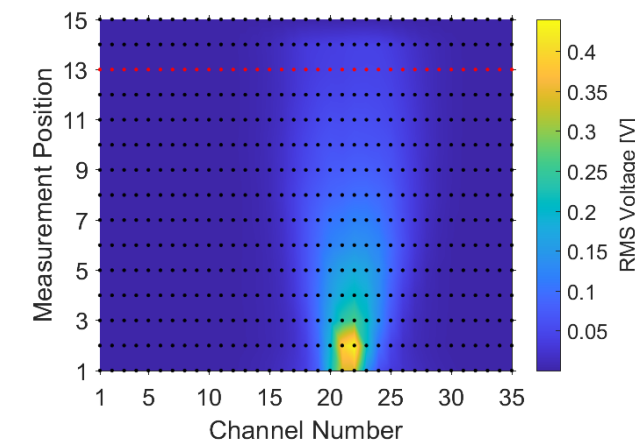
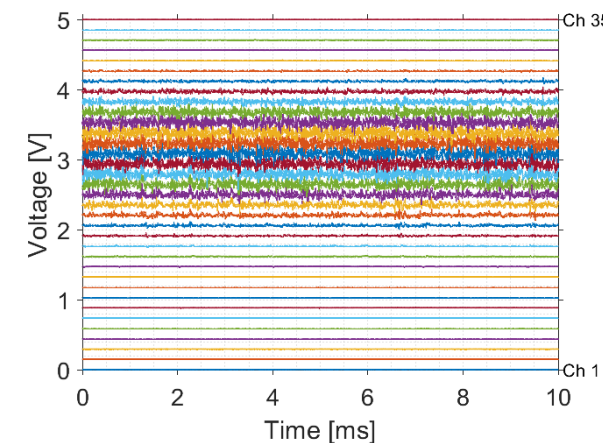
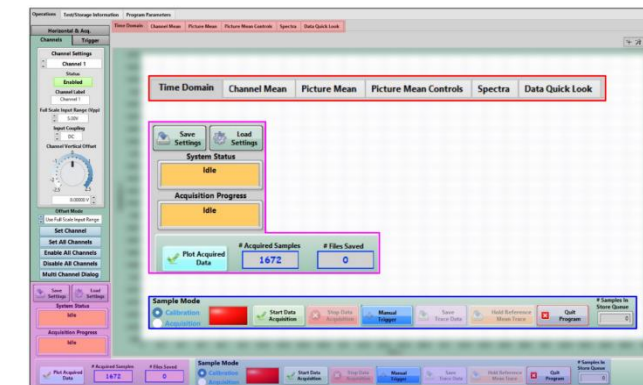
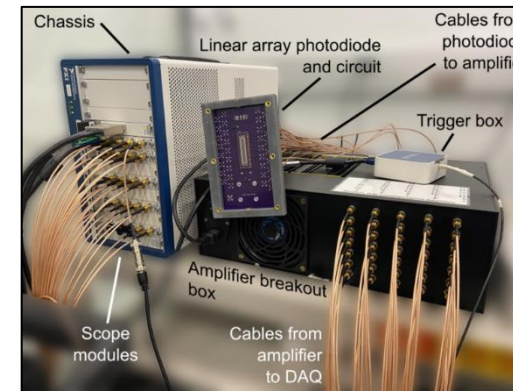
- Testing the full system (linear array photodiode, amplifier system, scope modules) incorporated into the line FLDI system
 - Compressed air jet centered on FLDI line, moved to different measurement positions away from line
- Left: elliptic beam shape incident on linear array between channel 21 and 22
- Middle: mean-subtracted voltage of every channel (measurement position 13)
- Right: root-mean-square (RMS) voltage of fifteen measurement positions of 35-channel system showing jet structure



What Was Accomplished

- Specially-tailored data acquisition system designed, constructed, and tested for use in line FLDI measurements

1. New 35-channel linear array photodiode mounted to a dedicated PCB, easily integrated into existing line FLDI setup
2. Signals from each channel amplified and conditioned in a 35-channel amplifier breakout box
3. 40-channel data acquisition system with updated graphical user interface
4. DAQ operation verified against previous FLDI oscilloscope
5. Linear array photodiode and amplifier circuit operation verified using tunable laser diode
6. Successful integration of all components into line FLDI setup to make measurements of a compressed air jet issuing from a small-diameter nozzle



- [1] Weisberger et al., "Multi-point line focused laser differential interferometer for high-speed flow fluctuation measurements," Applied Optics, Vol. 59, No. 34, 2020.
- [2] Weisberger et al., "Two-Line Focusing Laser Differential Interferometry of a Flat Plate Boundary Layer at Mach 6," AIAA SciTech 2021 Forum, AIAA-2021-0601.
- [3] Weisberger et al., "Two-Point Focused Laser Differential Interferometry Second-Mode Measurements at Mach 6," AIAA Aviation 2019 Forum, AIAA-2019-2903.
- [4] Bathel et al., "Two-point, parallel-beam focused laser differential interferometry with a Nomarski prism," Applied Optics, Vol. 59, No. 2, 2020.